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Grid Integration of Solar and Solar/Wind Hybrid Mini-Grid Projects: A Case of Solar/Wind Hybrid Mini-Grid Project Implemented by AEPC

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Abstract:
Alternative Energy Promotion Center (AEPC) has been scaling up renewable energy technologies through Mini-grid power supply in Nepal's off-grid areas in order to fulfill community electricity demands for both households and electricity-based enterprises. It is likely that, in some of the off-grid renewable energy (RE) mini-grid service areas, Nepal Electricity Authority (NEA) grid line might reach in near future. The objective of this study is to highlight success stories of solar and solar/wind mini-grids implemented by AEPC and for their longer-term sustainable operation grid integration policy of isolated mini-grid systems will require. Till the date AEPC has successfully electrified more than 20 rural communities through solar and solar/wind hybrid mini-grid systems. Some of these isolated mini-grid projects will seek grid interconnections in near future due to NEA distribution system expansion trend. When the isolated mini-grids will be connected to the national grid power network in future, the mini-grid can feed surplus electricity to the local utility grid line and will receive deficit electricity from the local utility grid system to serve the consumers connected to the local grid network. The methodology applied to this study is assessment of existing solar and solar/wind mini-grid projects, technological intervention required for grid integration, reviewing grid-connection policy of distributed renewable generations in the country and recommendation of relevant policy option for grid connection of rural mini-grids. Grid integration of isolated solar and solar/wind mini-grids will have positive impacts to the sustainability of the present isolated mini-grids, will help in retaining existing mini-grids end users, energy produced by mini-grid systems will be optimally utilized, the existing mini-grid power will contribute to stabilize weak national grid electrical parameters. The outcome of the study will recommend need of policy options as well as technological interventions in order to do grid integration of solar and solar/wind hybrid mini-grid systems in Nepal.

Keywords: Grid Integration, Mini-grid, Solar/Wind Hybrid, Sustainability

1 Introduction and background

1.1 Background and objective of the study

Access to modern energy is a prerequisite for achieving the millennium development goals (MDGs) and hence, United Nation (UN) has come up with sustainable energy for all (SE4ALL) program with the main objectives of (a) access to modern energy to every household by 2030, (b) doubling the improvement rate of energy efficiency by 2030, and (c) increase substantially the share of renewable energy in the total energy by 2030, from the year 2011 [1]. In order to achieve these goals Nepal should exploit its indigenous hydropower resources and renewable energy in the provision of reliable, affordable and accessible modern energy to every household. Nepal has huge potential to develop low carbon economy through its ample abundance of renewable energy resources such as solar energy, biomass, mini/micro hydro, wind energy etc. These renewable energy resources offer great opportunity to enhance energy security and for environmental sustainability. Although hydropower development is the national priority and will be taken as the lead energy resources, integration of other renewable energy resources is essential to meet objectives set by Government of Nepal (GoN) for enabling energy mix in the total national energy supply.

Nepal's energy resources are broadly divided into three categories of traditional, commercial and renewable energy. The traditional energy includes solid biomass fuels derived from plants and animal. The commercial energy includes electricity and petroleum products. Nepal completely depends on import for its required petroleum products. The demand of petroleum products has been continuously increasing, which indeed will likely to continue in the years to come. Figure 1 shows the

distribution of energy consumption by three major categories of energy resources in the year 2016/2017.

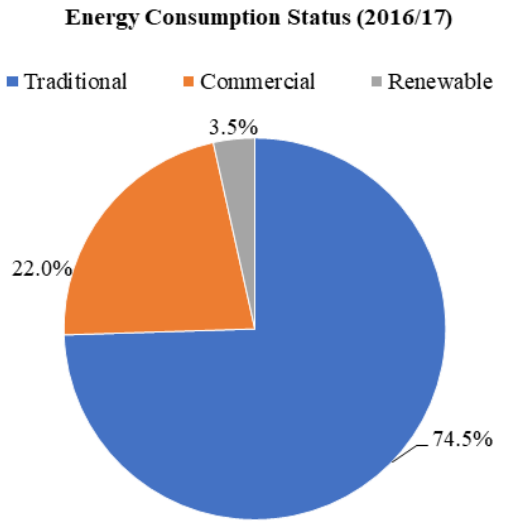

Figure 1: Share of Energy Consumption under three categories [2]

As observed, overall energy consumption is largely dominated by the use of traditional forms of energy such as fuel wood, agricultural residues and animal waste. The share of traditional biomass resources, commercial energy resources and renewable energy resources in 2016/017 are 74.5%, 22.0% and 3.5% respectively [2]. Renewable energy technologies (RETs) are serving to 3.6 million households of Nepal. Until 2016/017 the share of renewable energy in Nepal's overall energy mix reached to 3.5% from 0% in 2004 [3]. In terms of electricity access 18% of Nepalese households are served through RETs such as micro hydro, solar photovoltaic and wind energy [2].

On the path of up scaling renewable energy technologies, AEPC has been successfully implementing mini-grid based solar and solar/wind hybrid systems in the public private partnership (PPP) model for the electrification of off-grid communities. Many of these isolated mini-grid projects will seek grid interconnections in near future when the national grid power extends to the service areas.

The main objective of this study is to analyze the existing policy of distributed renewable energy system grid connection thereby seek policy support as well as technical intervention for the grid connection of isolated solar and solar/wind mini-grid systems.

1.2 Electricity supply situation of Nepal

Ministry of Energy, Water Resources and Irrigation (MoEWRI) has come up with White Paper B.S. 2075 and has set up roadmap for the next decade in the energy sector. In this regard, the role of Nepal Electricity Authority (NEA), state owned power utility, is vital to achieve key target of enhancing per capita annual electricity consumption by nearly 10 folds by 2028 as compared to that of 2018.

NEA is primarily responsible for planning, construction and operations for hydro-based electricity supply. There are various Independent Power Producers (IPPs), who generate electricity and under the Power Purchase Agreement with NEA sell the bulk power to NEA. The total population with access to grid electricity in Nepal has been reached about 70% [2].

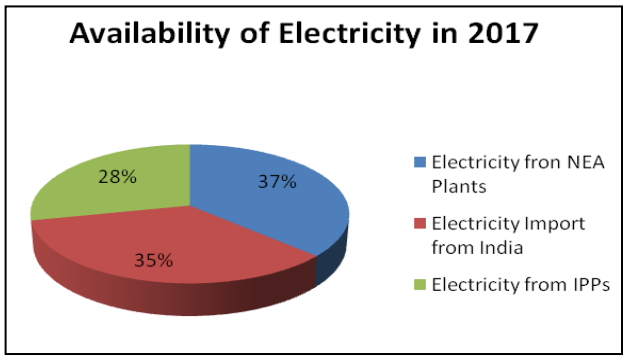

Figure 2: Availability of Electrical Energy in 2017 [4]

In the year 2017, total of 6,257.73 GWh electrical energy was available through the Integrated National Power System (INPS) out of which 2,305.17GWh was generated by NEA plants, 2,175.04GWh imported from India and 1,777.24GWh generated by IPPs [2].

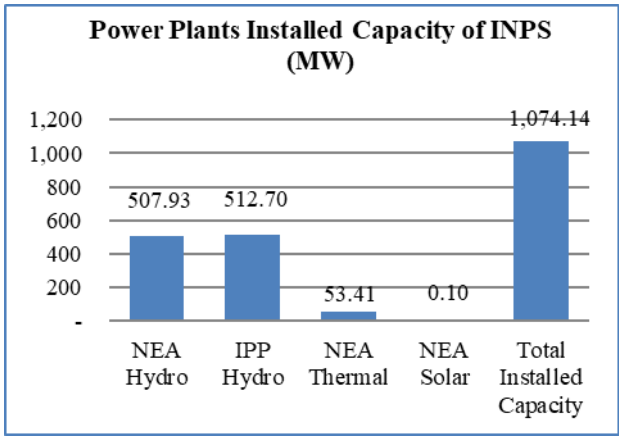

Figure 3: Availability of Electrical Power in 2017 [4]

At present, Nepal has a total installed power capacity is 1,074.14 MW out of which 47.3% is contributed by NEA owned hydro plants, 47.7% by IPPs hydro plants, 5% by NEA thermal plants and only 0.01% by solar photovoltaic (PV) as shown in figure 3 [2].

Nepal's per capita annual electricity consumption is 170 kWh which is the lowest in the South Asia. The Asian average is 1,040 kWh whereas China has the highest per capita electricity consumption of 4,280 kWh in the region as shown in Figure 4.

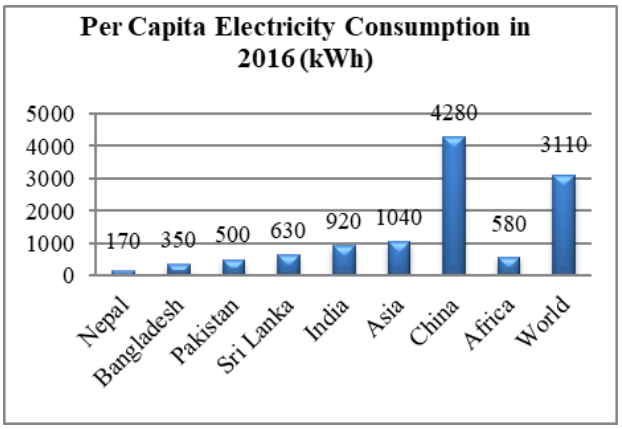

Figure 4: Per Capita Electricity Consumption [4]

Nepal's hydroelectricity system is dominated by run-of-the-river (ROR) power plants where only one-third of their installed capacity can be produced during winter or dry seasons. At least for the short and medium terms the energy mix for Nepal's power system is essential until sufficient energy generating capacity is achieved to meet all year demand.

1.3 Rationale of solar power development in the national energy mix

Because of its poor economic performance compared to other South Asian Countries and its total dependence on import of petroleum products, GoN requires strategic options for its energy security and sustainability. Current energy sector policies of Nepal are scattered in various documents and executive orders. An integrated energy policy covering all kind of energy resources including energy efficiency is essential. The prevailing institutional arrangement in energy sector is broadly based upon nature and type of energy resource, legal basis of the energy organization and scale of energy generation. Accordingly, a number of institutions exist in Nepal's energy sector. Mostly the micro scale electricity and other alternate energies are planned, managed and facilitated by AEPC which is under MoEWRI.

Along with biomass and micro or mini hydro energy systems, solar energy is one of the most promising resources that use abundant and free energy from the sun having clean, inexhaustible and environment friendly nature. Nepal, being located in favorable latitude, receives ample solar radiation. The average solar radiation varies from 3.6 - 6.2 kWh/m^2/day and having about 300 sunny days in a year [5]. The commercial potential of solar power for grid connection of Nepal is estimated to be 2,100 MW [6].

There is no viable alternative to solar power for rural electrification of large part of Nepal's rural population seeking to acquire Tier-3 level of energy services. The operation and maintenance cost of diesel generators for those remote locations is too high. Small hydro power plants need specific topographical conditions that are only found near a small percentage of users' settlement. Solar power generating systems do not need fuel or extensive infrastructure, it is easy and quicker to install. This option is found to be viable solution to meet basic energy needs in many locations of the country that are scattered with no access to national grid power.

The policy for integration of solar PV energy into national grid power system through NET Metering has already been formulated by GoN. Hence, the domestic grid connected solar photovoltaic (PV) plants can contribute day time power demand in the INPS. The grid-connected solar PV capacity addition will have positive impact in reducing NEA's distribution loss in the selected distribution center. NEA has announced launching "grid tied energy storage system" which aims to do a prototype to scrutinize the impact of energy storage system in the INPS.

1.4 Development of Solar PV grid connection in Nepal

A grid connected solar PV system or grid-tie PV system is electricity generation from solar photovoltaic modules or array that is connected to the utility grid line. A grid connected PV system consists of solar PV modules, one or several grid-tie inverters, energy meters and battery bank (for emergency storage purpose).

- Experience on grid connected PV in Nepal is still limited to a handful of small installations of Kilo-watt sizes such as at NEA office Min Bhawan, Nepal Engineer's Association Building Pulchowk, NEA Training Center Kharipati, Center for Energy Studies (CES) Pulchowk Campus, RIDS-Nepal Office Imadol, Kathmandu UpatyakaKhanepani Limited (KUKL) Dhobighat, Lalitpur and MK Paper Mills, Bhumahi, Nawalparasi.
- Nepal's first Megawatt scale grid-connected solar power plant of 25 MWp is under construction in Devighat, Nuwakot District. NEA year review report of 2017/18 stated that the total of 60 MWp solar

power plant capacities is being developed by different IPPs.

- GoN has received Grant of USD 20 million from Strategic Climate Change Fund, under ADB administration of SASEC Power System Expansion Project. NEA will utilize 18.5 million of the Grant as viability gap funding (VGF) to purchase solar power from the eligible solar power developer. The solar power developer will be encouraged by the upfront payment they would receive from NEA for the power they sell up to June 2022. Under this scheme, NEA will purchase power from grid tied solar plant for 25 years at the posted rate of NRs. 6.60. The VGF will be utilized to fill the gap of posted solar power purchase rate of NRs. 6.60 per kWh and the competitive rate quoted by the Solar power Developer for up to June 2022 [6].
- Grid-tie Energy Efficient Solar Water Pumping and Irrigation project initiated by NEA aims to provide sustainable solution to the farmers suffering from low voltage in water pumping. It will also provide a scheme to the existing solar water pumping projects to sell the surplus electricity to grid in Net Metering scheme. The project will also cover existing AC pumps in irrigation to be replaced by efficient pumps with grid tie provision.
- By decision dated B.S. 2074/08/06 GoN formulated policy guideline for solar power grid-connection. The guideline includes roof top solar grid connection, institutional and commercial solar power grid connection. It has covered household roof top solar power system sizes from 0.5 kWp to 10 kWp. Similarly, institutional solar power system sizes of above 10 kWp and commercial solar power plants of above 500 kWp sizes are included in the policy guideline.

1.5 GoN subsidy policy for solar and solar/wind hybrid mini-grids

As per policy, the solar or solar/wind hybrid mini-grid projects will be eligible to receive subsidy if the site is not accessible to national grid power supply and no other means of electrification exists.

The upfront capital subsidy to solar or solar/wind hybrid mini-grid system is provisioned for the power system from 5 kW to 100 kW installed capacity. The upfront capital subsidy is allocated from NRs 150,000 to 175,000 per kW as generation subsidy plus NRs 28,000 to 32,000 per household as distribution subsidy but not exceeding NRs 430,000 to NRs 495,000 per kW in total, depending on the remoteness of the project site [7].

1.6 Rationale of promoting solar and solar/wind hybrid mini-grids

Small-scale renewable systems can bolster the country's energy security by diversifying sources of energy and thus can reduce dependence on imports. Solar PV technology is one of the widely used renewable energy technology in the country where about 800,000 households are electrified through solar home lighting systems to meet basic electricity needs in off-grid areas [3]. About 200 kW solar/wind hybrid isolated mini-grid projects for the off-grid communities have been already implemented. With the support from Asian Development Bank (ADB), South Asia Sub-regional Economic Cooperation (SASEC), AEPC is implementing additional 500 kW solar and solar/wind hybrid mini-grid projects in order to serve rural households as well as promote rural enterprises thereby supporting local economic activities.

For the country like Nepal where national grid extension to all rural communities is challenge, clean and modern electricity service through solar and solar/wind hybrid systems is experienced to be the best feasible option. With the success of previously implemented mini-grid projects, there has been strong and increasing interest coming up from the rural communities.

2 Methodology

2.1 Literature review

The study is accomplished to identify current provision of grid integration of isolated mini-based renewable energy technologies in Nepal. The primary information for the study is acquired from one of the mini-grid project sites whereas the secondary data for the study report were collected mainly from various policy related documents, relevant previous studies. The previous study reports published by Nepal Electricity Authority, Alternative Energy Promotion Centre Nepal, Ministry of Energy Water Resources and Irrigation Nepal, Water and Energy Commission Secretariat Nepal, International Energy Agency, were mainly referred for this study. The following secondary data were collected from NEA and AEPC.

- An in-depth review and assessment of existing solar and solar/wind mini-grid electrification efforts undertaken by AEPC.

- The database of off-grid solar and solar/wind mini-grid projects implemented and documented by AEPC, and supplemented by field visits to the selected project sites. The database covers, among others a range of technologies, geographical locations, capacity of the plants, ownership and management arrangement.
- Existing subsidy policy for renewable energy technologies focusing on the community electrification services
- Review of grid-connection policy interventions initiated for the distributed renewable generations in Nepal
- Technical challenges for the grid integration of isolated mini-grid systems
- Feasibility of grid connection of solar and solar/wind hybrid mini-grid projects

2.2 Assessment of status of solar and solar/wind Mini-grids

A mini-grid consists of an electricity generator interconnected to a distribution network that supplies electricity to a localized group of customers. With the technological advancement and improvement in supply chain, AEPC scaled up small scale solar home systems and micro wind turbines to fulfill household, community and enterprise electricity demand in the rural areas. Currently AEPC is implementing 350 kWp solar mini-grid and 337 kW solar/wind hybrid mini-grid projects in off-grid areas in 20 different sites [3].

With the support from United Nation Environment Program (UNEP), AEPC implemented solar and wind energy resource assessment (SWERA) project from March 2003 to December 2006. As indicated by SWERA report, the wind potential of 3,000 MW exists in the country even by considering only 10% of total feasible area with wind power density of greater than 300 W/m^2 [6].

The major breakthrough for solar/wind mini grid (SWMG) hybrid technology in Nepal happened in 2010 by implementing 10 kW wind turbines and 2 kWp solar PV power hybrid pilot project supported by Asian Development Bank (ADB), RETA Project at Dhaubadi village of Nawalparasi District. Following the pilot project, AEPC implemented various solar and solar/wind hybrid mini-grid projects in off-grid settlements (Tables 1 and 2).

Table 1: Status of Solar Mini-grids (SMG) Implemented by AEPC (AEPC, 2018)

S.N.	Project Name	District	Installed Capacity
1	Dubung SMG	Tanahu	17kWp
2	Harkpur SMG	Okhaldhunga	31kWp
3	Kaduwa Solar Mini-grid	Khotang	21kWp
4	Chyasmitar SMG	Khotang	17kWp
5	Ramitekhola SMG	Morang	30kWp
6	Olane Solar Mini-grid	Panchthar	25kWp
7	Rithachaupata SMG-1 *	Darchula	21kWp
8	Rithachaupata SMG-1 *	Darchula	13kWp
9	Gutu SMG *	Surkhet	100kWp
10	Sugarkhal SMG *	Kailali	75kWp
	Total Capacity		350kWp

** Projects under construction*

2.3 Field visit and site analysis

As a case study a 70 kW Saptami Solar/Wind Hybrid Mini-grid Project of Miklajung Rural Municipality Ward-

Table 2: Status of Solar/Wind (SWMG) Hybrid Implemented by AEPC (AEPC, 2018)

S.N.	Project Name	District	Wind (kW)	Solar PV (kWp)	Total Size
1	Dhaubadi SWMG	Nawalparasi	10	2	12 kW
2	Bhorleni SWMG	Makawanpur	10	15	25 kW
3	Harrekanda SWMG	Surkhet	3	5	8 kW
4	Tatopani SWMG	Jumla	15	11	26 kW
5	Kamalbazaar SWMG	Achham	20	11	31 kW
6	Parakatne SWMG	Bajhang	15	10	25 kW
7	Narakot SWMG	Jumla	50	30	80 kW
8	Mityal SWMG	Palpa	10	15	25kW
9	Chisapani SWMG	Sindhuli	20	15	35 kW
10	Saptami SWMG	Panchthar	20	50	70 kW
			163 kW	**146 kWp**	**337 kW**

2, Panchthar District, is considered. The project has been recently constructed which is grid-ready system for future grid connection. Technical information for viability of grid-connection such as local distribution network, power conditioning devices, grid voltage level and enabling policy of isolated solar/wind hybrid system grid connection analyzed. The field visits and site analysis of mini-grid project intended to gather project related information through informal conversation and stakeholder's interview. The primary data were gathered from personal interview with the government line agencies and the stakeholders' consultations by conducting mini-grid project site visits. During the field visit data and information gathering, informal meetings with the users' committee, rural municipality officials and NEA local office representatives have been conducted.

2.4 Analysis for grid connection possibility of mini-grid

Analysis of local grid expansion plan of NEA community electrification section is analyzed for possibility of future grid connection at the selected site of 70kW Saptami solar/wind hybrid system. As guided by Community Rural Electrification By-Law 2071, NEA sells bulk power to the Community Rural Electrification Entities (CREEs) and CREESs are responsible for operation and management of electricity distribution within the area. NEA provides services up to 11 kV line and the CREE's are responsible for managing 400/230V line. The analysis of NEA grid expansion plan at the selected project site of Panchthar District shows that, there is high possibility of arrival of NEA grid power through Rake-Rabi-Chisapani 33 kV Transmission Line Project [4]. The grid expansion scheme includes construction of 25 km of 33 kV line, 40 km of 11 kV line, 40 km of LT distribution line, construction of 33/11 kV, 6/8 MVA substation at Chisapani Panchami and 33 kV Switching Station at Ranke, Panchthar. In future when the grid connection of mini-grid system is made, Saptami solar/wind hybrid mini-grid users' committee may purchase bulk power or sell surplus power to CREE of NEA to provide electricity service to the local community.

The Saptami solar/wind hybrid mini-grid system consists of 50 kWp solar PV array and 20 kW wind turbines as power generation components. The system has 576 kWh size battery bank which will be charged through battery inverters (or islanding inverters). The system also consists of 50 kW solar PV inverters that can supply direct power to the day time electrical loads and those PV inverters are grid-tie inverters which can directly feed power to the utility line after grid connection. The 11 kV and 400 V transmission and distribution system components are constructed complying Nepal's national grid system. Technical requirements to be fulfilled for interfacing or synchronizing the mini-grid system with the national grid network at Saptami site are matching phase sequence, frequency and voltage. Solar and Wind energy is intermittent in nature that means rapid change in voltage may happen which can result in voltage flicker. However, the large battery bank of 576 kWh storage capacity which can handle fluctuations but need to consider potential voltage and frequency fluctuation from long running utility line.

3 Details of Case Study

Table 3: Technical Components of 70kW Saptami Solar/Wind Hybrid Mini-grid System

System Components	Quantity	Size/Unit	Total
Solar PV Array	50 kWp		
Wind Turbine	20 kW		
VRLA Tub Gel Batteries	576 kWh		
PV Inverter 3-Phase	2	25 kW	50 kW
Battery Inverter 1-Phase	9	6 kW	54 kW
Transmission and Distribution	**3 Phase**	**1 Phase**	3.1 km
	11kV = 1.4 km, 400V= 1.4 km	230 V= 0.3 km	
Transformers	2	50 kVA	100 kVA

In March 2018, Alternative Energy Promotion Center Nepal started implementing 70 kW solar/wind hybrid mini-grid project to electrify 110 households, supply power to a Tea Industry and to power small to medium scale Enterprises within Saptami Bazaar of Panchthar District. The project is implemented in the public private partnership modality where the ownership of the project will be transferred completely to the local community after three years of completion. At Saptami Sarangdanda project site strong wind followed by sunny days complements each other in power production. A new solar/wind hybrid power system is expected to boost local livelihood by offering various energy opportunities. This is a perfect example of AEPC work with the local community of Saptami Bazaar to serve with the clean, decentralized and sustainable energy intervention. AEPC has planned to continue electrifying additional villages

with the solar/wind hybrid mini-grid projects within next two years period. It is a step towards bigger role of renewable energy in Nepal where an abundance of sun, wind and hydro offer reliable, cost effective, low carbon power solutions to the rural communities. Major system components of 70 kW Saptami Solar/Wind Hybrid system are summarized in the table 3.

4 Conclusions

a. There have been good evidences of a significant progress in community rural electrification by solar and solar/wind hybrid mini-grid technologies in the recent years. The motivation for off-grid energy projects aimed to increase local economic activities, access to modern form of electricity for the households as well as community services to operate electrical appliances and businesses.

b. Enabling policy arrangement for off-grid community electrification projects requires priority attention. Policy uncertainty about grid extension, poor access to credit and absence of formal financial institutions at the local level discourage private entrepreneur to venture in to the sector. Hence, the policy should protect mini-grid system developer against the grid extension threat; any assurance in this respect will improve the investment prospects.

c. As AEPC has been implementing grid compatible and grid ready solar or solar/wind hybrid mini-grid projects that are presently located far from the national grid power network, grid integration is technically viable with little technical arrangements at mini-grid power plants when grid will reach in future.

d. As provisioned for grid connection of roof top, institutional and commercial solar power plants in current policy guideline, the clear space should be provided to isolated community based solar or solar/wind mini-grid systems for grid interconnection to ensure their sustainable operation for modern electricity services.

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